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RESEARCH PAPER

Linking National Forestry Reform Through Forest Concession Policy and Land Cover Change

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Abstract In Peru, a new forest reform process laid the foundation for the establishment of a large sector of private small and medium-sized forest enterprises to practice responsible forest management. This paper analyzes the influence of a newly established concession system on forest landscape change. Specifically, the paper examines whether the concession system promoted and increased land-cover changes and changed fragmentation patterns between 2001 and 2010. Classified Landsat images at 2-year intervals from 2001 to 2003 and 2006 to 2010 were used to examine trajectories in forest, non-forest and regrowth areas. Non-linear changes were found to have occurred in each of the forest classes. Changes in fragmentation varied in size, density, aggregation and configuration over the study period. Forest reforms account for changes in specific land-cover classes through pattern dynamics within timber concessions. However, not all results relate to landscape pattern metrics. Although new forest legislation has been important in reorganizing the forest sector, other causal factors including levels of technological and managerial expertise, credit availability and law enforcement structures play a decisive role in the successive implementation of forest legislation.

Keywords Forest legislation · Pattern metrics · Private small-medium forest enterprises · Peru

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Introduction

Monitoring land-cover changes (LCCs) in large tropical forests is still a crucial objective for scientists due to the possible impacts of these changes on the forest ecosystem. The principal causes of deforestation are reasonably well understood (Rudel 2005). For example, it is well known that small-scale agriculture, large cattle ranching and unmanaged timber extraction account for increased deforestation in the Amazon (Cattaneo 2002; Wood and Porro 2002; Lambin and Geist 2003). However, the more indirect influence of other factors on LCCs has not been systematically examined by the scientific community (Lambin and Geist 2006; Salo and Toivonen 2009).

Forest policies that oversee all aspects of forest and timber resources need to be addressed, particularly since policies that affect forest activities have changed substantially over time, as is the case in most countries sharing the Amazon basin. For example, in the past two decades, forest policy changes have resulted from global concerns that have led to efforts to stop tropical deforestation and to promote sustainable forest management (SFM) practices (Cashore and Newsom 2004; Nussbaum and Simula 2004).

In Brazil, the introduction of the Brazilian National Forestry Policy spawned high expectations of reduced conventional logging (based on the selective extraction of highly valuable species without any forest management consideration) and illegal logging through regulated concessions (Verissimo et al. 2002; Nepstad et al. 2004). In Peru, the introduction of land-use policies that promote SFM has helped preserve protected areas to some extent (Oliveira et al. 2007). In Africa, the granting of logging concessions has played a role in protecting land by reducing the risk of forest conversion (Clark et al. 2009).

The Amazon timber industry has contributed greatly to the clear-cutting and burning of forest, leading to deforestation (Nepstad et al. 1999). Increased forest damage associated with logging is linked to improved road networks that further open access to agricultural expansion and secondary roads (Nepstad et al. 2001). Conventional logging has a broader impact on forest damage, while SFM through selective logging practices offers sustainable alternatives for preserving forests. The impact of conventional logging has been easier to detect than that of selective logging. Nonetheless, improved applications of remote sensing techniques have allowed in-depth reporting on the impact of selective logging (Asner et al. 2002; Souza et al. 2005; Asner et al. 2005).

In addition to the analysis of the environmental effects of SFM, it is crucial to follow the institutionalization process of SFM within timber concessions in many tropical countries. In Latin America, in particular, implementing SFM has encountered several challenges due to the lack of law enforcement and weak incentives to adopt reduced impact logging. The strong and continuous presence of an informal timber sector has also resulted in low-priced illegally logged timber, which subsequently weakens SFM practices (FAO 2009). Growing incomes that stem from illegal logging activities are increasingly shaping market mechanisms (Killeen 2007; EIA 2009b) and accepted as de facto, posing increased hardship in the fight against corruption (Cerdán 2007; Youatt and Cmar 2009) and reducing the

sustainability of forest resource use. A study by the Environmental Intelligence Agency (Urrunaga et al. 2012, 3) concluded that ‘corruption and illegality remain the norm in the forestry sector, not the exception’. The same study reported that actual timber exports are 1.5 times as high as reported timber exports, indicating that approximately 80 % of timber exports are illegally harvested logs. Moreover, logging laws and regulations have not been consistently enforced, leaving more room for informal practices and widespread cases of law infringements (Smith et al. 2006; Sears and Pinedo-Vasquez 2011).

Peru, with the second largest area of natural forest in the Amazon basin (Schwartz 2004), underwent significant forest policy reforms in 2000 with the aim of improving the management of its forests. Before 2000, forestry activity was regulated by the 1975 *Forestry and Wildlife Law* (FWL No. 21147), which facilitated the admission of small-scale loggers to free-access forests in the country by allowing them to log up to 1,000 ha, for a period of two to 10 years, without a management plan. In practice, however, large-scale loggers abused this legislation by hiring many small loggers to request 1,000 ha contracts and by harvesting much larger extensions of forest without a management plan and without fulfilling the obligations required by larger contracts (Cossío 2009). Thus, the large number of small and dispersed contracts and the lack of effective control during the implementation of the 1975 FWL led to forest over-exploitation, widespread proliferation of illegal logging, and emergence of a patronage relationship between small- and large-scale loggers (Chirinos and Ruíz 2003).

The 2000 FWL (No. 27308) established a new forest regime that introduced a series of basic concepts for SFM. The new Peruvian forest regime promotes the use of forest resources by granting long-term forest concessions (for 40 years) in permanent production forests through public bidding processes. This management modality is intended to encourage small and medium-sized entrepreneurs either individually or through the formation of so-called small or medium-sized forest enterprises (SMFE). Forest concessions as well as ‘forest permits’, which are granted to indigenous communities and small farmers, require the elaboration of management plans and payment of a harvesting fee. Concessionaires have to file a general forest management plan, which provides the general planning framework for the 40 years of the concession contract, as well as annual operating plans (AOPs) that set out in detail the forest inventory of the annual cutting area (Cossío 2009).

Following the implementation of the 2000 forest regime in Peru, new logging roads were opened in forest concessions. At the same time, new highways led to diverse changes at a faster pace in the southeastern Peruvian Amazon (Perz et al. 2007a, b), a region of significant ecological gradients, high biodiversity (Terborgh 1999; Myers et al. 2000; Killeen 2007) and diverse cultural and social landscapes (Dourojeanni 2006; Dourojeanni et al. 2009). Since 2006, the implementation of the IIRSA SUR (Initiative for the Integration of Regional Infrastructure in South America) infrastructure development project has started to affect land-use and land-cover changes (Dourojeanni 2006; Mendoza et al. 2007), while the paving of the Inter-Oceanic road has further simplified the transportation of timber products and stimulated the opening of secondary roads.

Given the relevance of the southeastern Peruvian Amazon as an important timber production area, it is imperative to assess empirically the influence of recent forest policies on the forest landscape. For the purpose of this study, SFM[1] is defined as the set of new forest regulations resulting from the 2000 forest policy regime and promoted via timber-concession allocation policies.

The main objective of this study is to assess whether the implementation of forest management practices have affected LCC by increasing or decreasing forest area and by altering forest structure and forest fragmentation. Patterns of LCC and changes in spatial configuration are examined in 63-forest concession contracts for the period 2001–2010 in the southeastern Peruvian Amazon. Surveys conducted with policy-makers, key experts and timber concession representatives reveal information as to how the concession system is linked to forest cover changes. By evaluating forest changes based on satellite imagery linked to fragmentation analysis and policy implementation, a new systemic approach and valuable technique is developed for assessing LCC and the effectiveness of policy change.

The Study Site

The study was conducted in the region of Madre de Dios, covering an area of 85,300 km^2 with altitude ranging from 183 to 3,932 m above sea level (Fig. 1). The landscape presents two biophysical units: a ruggedly mountainous area, located in the southwest of the region, comprising shallow soils of low natural fertility, and a lower area with undulating relief where floodplains and low hills dominate. The annual rainfall is about 2,260 mm concentrated in a rainy season from October to April. The mean annual average temperature in Puerto Maldonado, the capital of the region, is 26 °C (INEI 2004).

Madre de Dios comprises three provinces: Tahuamanu, Tambopata, and Manu. Tahuamanu is the smallest, the least populated (INEI 2008), the least logged, and has the largest volume of mahogany (Cossío 2009), for which the area has experienced increased attention among loggers and conservationists (ITTO 2005).

Madre de Dios is the main centre of biological diversity and endemism in Peru (CTAR-IIAP 2000) and is home to approximately nine Amazon Indian groups (Huertas Castillo and Garcia 2003). It also has the smallest population in Peru at the regional level; however, since 1993 it has experienced the largest proportional increase in population (63.5 %) among all regions (INEI 2008). The indigenous population is settled in territories legally recognized as indigenous land communities, while the rural non-indigenous population is settled in small communities along rivers and roads. Both groups are engaged in an array of activities, including hunting, fishing and gathering in protected areas, agriculture and ranching, Brazil nut harvesting, logging, and gold mining (Cossío 2009; Chávez Michaelsen et al. 2013).

[1] According to this law a series of basic concepts for SFM were introduced and understood as more responsible practices, including: harvesting of forests through long-term contracts (40 years); obligation to present management plans; payment of a harvesting fee for the total area under concession; and a legal framework to promote forest certification.

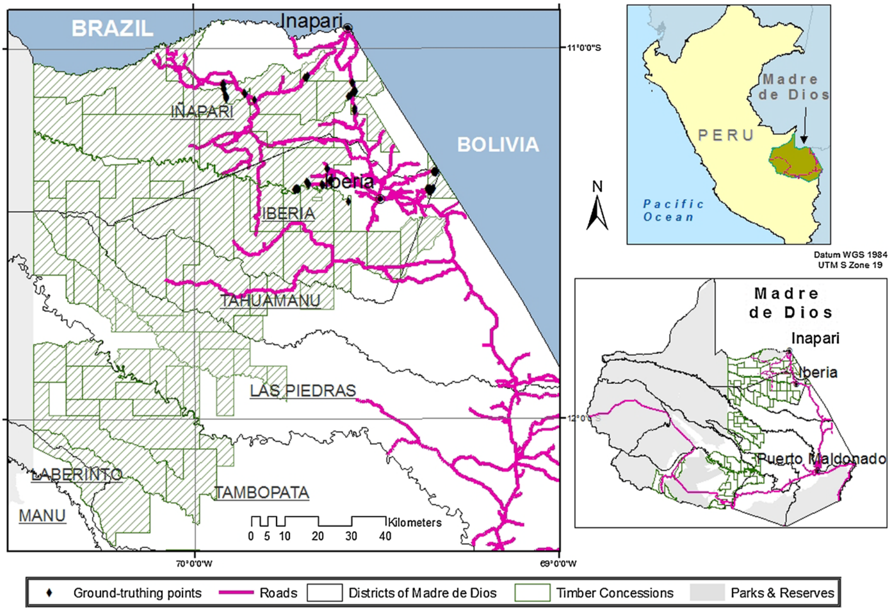

Fig. 1 Map of Madre de Dios Region in Southeastern Peru

Madre de Dios is one of the main centres of timber production in Peru, and logging is an important economic activity, which employs 65 % of the economically active population (Chirinos and Ruíz 2003). However, the economically active population also engages in Brazil nut harvest, agriculture, ranching, commerce, mining and other activities. The three timber species most harvested in Madre de Dios are *Cedrelinga catenaeformis* (tornillo), *Chorisia integrifolia* (lupuna), and *Coumarouna odorata* (shihuahuaco), which accounted for almost 44 % of the total timber volume harvested in the region in 2012 (MINAG-DGFFS 2012). However, more species are being harvested, mainly due to increasing timber prices, rising demand for less traditional timber species, and a reducing export quota for mahogany and cedar since 2007 (Cossío 2009; Urrunaga et al. 2012).

Research Method

A spatio-temporal analysis of LCCs was performed using data applying to before and after the implementation of timber-concession allocation policies (2001–2010) to assess the degree of forest fragmentation in designated timber concession areas. It is hypothesized that timber-concession allocation policies affect LCCs (increase or decrease forest cover) by altering forest structure and increasing forest fragmentation. LCC classes are represented by changes from forest to non-forest or to secondary forest and secondary forest or non-forest to forest. Expected LCCs relate to changes in spatial heterogeneity as well as in the degree of forest fragmentation (McGarigal et al. 2012). Changes in spatial homogeneity and

heterogeneity are based on LCC classes (a more homogeneous forest is equivalent to lower deforestation or more forest, while a more heterogeneous forest is equivalent to higher deforestation or less forest). Degree of forest fragmentation is based on changes in the indices of the spatial composition and configuration of the landscape.

The time period of analysis of 2001–2010 was chosen because of its significance to the forestry reform process; the overall sample period was divided into specific sub-periods of analysis linked to satellite images and forest fragmentation via landscape-level and class-level analysis (Table 1). Year 2001, immediately prior to implementation of the new forest concession regime, represents the operation of small contracts. The sub-period 2003–2006 represents a grace period when the government allowed concessionaires to manage their forests without the costly elaboration of a current forest inventory of their total areas (but using only a governmental study and complemented with the elaboration of annual operating plans), and within a regime of discounts for the payment of their harvesting fees (Cossío 2009). The sub-period 2007–2010 is a period where timber concessionaires had to conduct forest management under 'regular compliance regulations' (i.e. they were required to develop a forest inventory of the whole concession area and did not receive discounts in harvesting fees.

The analysis assumes that the change from initial concessional compliance regulations to regular compliance regulations within SFM after 2006 affected deforestation and fragmentation. For example, timber concessions that were financially and institutionally struggling in previous years may encounter difficulties complying with the new requirements, such as the payment of harvesting fees, submission of management plans and elaboration of censuses (Cossío et al. 2011a). According to World Bank (2007), less than 10 % of granted concession enterprises were in conditions to meet their harvest fee, which clearly indicates strong economic and operational problems. Deforestation was expected to be higher before the implementation of the forest concession regime (prior to 2002) and lower during its implementation and grace period (2003–2006).

After 2006, various LCC and fragmentation outcomes could be expected. If timber concessions have the financial capacity to pursue and comply with all the new regulations, deforestation would be expected to decrease. However, if compliance with the new regulations hinders timber management, deforestation rates would be expected to be higher because concessionaires would end up ignoring the regulations such as those related to extraction and transport authorization. Table 1 shows the expected outcomes of the study and describes how the fragmentation indices vary according to deforestation measures. The study does not measure the ability of concessions to comply with all regulations on the ground other than corroborate these assumptions with a survey conducted on timber concessionaires and key forest representatives as well as analyze data from previous studies (Cossío 2009; Cossío et al. 2011a). Finally, the study assumes that policies leave imprints on the landscape within a 1- to 2-year satellite image interval, meaning that the effects of policies enacted in 2001 may be visible in 2002–2003.

Table 1 Changing land-cover classes and expected land cover and fragmentation outcomes in Madre de Dios, period 2001–2010

SFM policy	Satellite imagery	Expected land cover	Fragmentation
None	Landsat ETM+ July 29, 2001	Baseline	Baseline
2002–2006 SFM grace period	Landsat TM September 13, 2003 Landsat TM May 16, 2006	Homogenous forest: Increase in: forest areas Decrease in: non-forest areas	Expected metric indices[a]: Increase in: CONTAG, LPI, GYRATE, CA (F, SF), CLUMPY (SF) Decrease in: NP, ED, CA (NF)
2007–2010 SFM regular compliance regulations	Landsat TM May 8, 2008 Landsat TM September 16, 2010	Heterogeneous forest: Increase in: non-forest areas Decrease in: forest areas	Expected metric[2] indices: Increase in: NP, ED, CA (NF) Decrease in: CONTAG, LPI, CLUMPY (F), GYRATE, CA (F, SF)

The *Forestry Law* was enacted in 2000, rules were established in 2001 and law was officially implemented in 2002

See Supplementary materials for more description on the selected indices

[a] The expected class and landscape metric indices are: *NP* number of patches, *ED* edge density, *CONTAG* contagion, *LPI* largest patch index, *GYRATE* radius of gyration, *CLUMPY* clumpiness, *CA* class area

Remote Sensing and Forest Fragmentation Analysis

Table 2 provides an overview of the 63 forest concessions chosen for this study. Figure 1 includes a striped area, which corresponds to the chosen 63 timber concessions. This predefined concession boundary area is located within the worldwide reference system (WRS) of the satellite imagery Landsat path and row 3/68 scene,[2] and includes partial areas of 63-forest concession contracts from the provinces of Tahuamanu and Tambopata (Table 2 and Fig. 1). The study area does not include the total area of all 85-forest concession contracts in Madre de Dios, because the study aimed to fit the forest concession area within the WRS 3/68 satellite scene. Moreover, it includes concession areas in close proximity to major and secondary roads. Timber concession areas limit and, in some cases, overlap agricultural titled lands (Chávez Michaelsen et al. 2013). These areas were removed from the analysis.

In order to measure LCCs and perform the spatial pattern analysis techniques that compute forest fragmentation, five 30-m resolution Landsat satellite images were obtained, as listed in (Table 1): (1) ETM[3] for 2001 (July 29); (2) Landsat TM 5 for

[2] World Reference System (WRS) is a path and row-comprised global grid system used to locate a rectangular scene of satellite imagery.

[3] Enhanced Thematic Mapper Plus satellite instrument.

Table 2 Forest concessions chosen for this study within the provinces of Tahuamanu and Tambopata, Madre de Dios

Forest concession area and contracts	Study area	Madre de Dios region
Original area granted as forest concessions (ha)	986,402	1,309,620
Granted contracts (No.)	63	85
Cancelled contracts (No.)	7	9
Cancelled area (ha)	77,081	133,900
Area under current management (ha)	909,321	1,175,720

Source: OSINFOR (2009)

2003 (September 13); (3) Landsat TM for 2006 (May 16); (4) Landsat TM for 2008 (May 5); and (5) Landsat TM for 2010 (September 16). The pre-processing of all images involved, first, the geometric rectification and registration of the 2001 scene to a 1:100,000-scale topographic map (UTM[4] WGS[5] 1984 Zone 19S coordinate system) and, second, an image-to-image geometric rectification of the remaining images to the 2001 base image. All images were radiometrically calibrated using methods described by Green et al. (2005).

Classification procedures included the Tasseled Cap transformation of all images, unsupervised classification through isodata, and a subsequent maximum likelihood supervised classification that generated three-class maps for all years. Water, clouds, and shadows were masked out of every image. Ultimately, the land-cover classes were grouped into the following three categories: (1) forest (F), (2) built-up area/non-forest (NF), and (3) secondary forest (SF). Secondary forests incorporate vegetation left to regenerate without intervention after logging extraction. Non-forest areas relate to timber concession roads, primary roads, skid trails and logging camps. The forest class covers alluvial and non-alluvial forest as well as the large areas of bamboo forest.

In order to assess impact of SFM practices, a remote sensing analysis should detect forest degradation rather than deforestation. Logging practices lead to understory thinning and carbon stock decline, which in turn lead to forest degradation (Herold et al. 2011). However, measuring the extent of forest degradation and forest management is much more difficult than measuring deforestation (Defries et al. 2007; Sasaki and Putz 2009) because degradation does not involve canopy removal. Fagan and Shoobridge (2007), for example, showed that distinctive sawn timber quartering techniques within the selective harvesting of timber lead to forest-cover change. Nonetheless, this study focuses on 'deforestation' rather than 'forest degradation'. Deforestation measurements are herewith understood as the removal of tree stand and its conversion to a temporary or permanent non-forest use, which encompass the opening of logging roads, secondary roads, skid trails and milling operations. Notably, deforestation related to agriculture expansion occurs mainly outside concession areas in disputed land-tenure overlays between concessions and agricultural areas. For this particular study, deforestation in titled agricultural land was not part of the analysis, and all of these overlap areas within timber concessions were removed.

[4] Universal Transverse Mercator geographic coordinate system.

[5] World Geodetic System standard coordinate frame/reference surface.

The authors conducted semi-formal surveys with the public sector and with timber concessionaires to relate LCC to current and previous forestry law. The study benefited from field data acquired from 2005 to 2007 based on two types of surveys performed on 27 forest key actors (forestry experts from NGOs, University professors, governmental representatives, and consultants) and on 27 managers of SFMEs (Cossío 2009). The survey of timber concessionaires provided information on outcomes of forestry laws and regulations and how these affected the structure and functioning of the timber concession, data on evaluation of concession activity prior- and post-forestry law restructuring, amount of timber extracted and description of specific sustainable forest management practices. Both surveys further included data on forest organization and management feasibility, capacity and restrictions, all focused on aspects supporting or hindering the viability of SFMEs (Cossío 2009). These surveys obtained on the performance and main challenges of SFMEs allow linking SFM with the survey data on the concession system and LCC.

The post-processing stage required classification validation through a field site sampling and registration process using a handheld GPS for 2003–2004 (295 plots), and 2010 (498 plots) from which data were collected at the province level (as reported by Chavez 2009; Chávez Michaelsen et al. 2013). About 30 % of these ground-control points fall within the 63-forest concession contract areas. Ground-truthing within timber concession areas helped validate land-cover classification and provided insights into the structure of regrowth stages, mainly by identifying the total height and ground cover of dominant species.

Spatial land-cover patterns were then analyzed for each land-cover class by using a range of selected metrics that describe the composition and configuration of the entire landscape. Metric indices derived from satellite-based land-cover classification techniques provided useful information on the spatial character and distribution of patches across the landscape.

For example, landscape- and class-level metrics capture representative patterns through distinctive degrees of landscape heterogeneity and fragmentation (Southworth et al. 2004).

The 63-forest concession contract areas were located within the 2006 official timber cadastral concession file.[6] Forest, non-forest and secondary forest classified images were processed, transformed into a 30×30 m grid format and inserted into FRAGSTATS 4.1 software to compute five landscape indices and four class metric indices. While the areas related to selected timber concessions delimit the boundary of the granted concessions in 2002, the analysis gives no indication of exactly where timber was extracted within the selected timber concessions. There is no information on annual cutting areas, suggesting that timber extraction may have occurred in different areas and during different years. The study therefore reports LCCs and changes in landscape patterns for the studied timber concession area without distinguishing the location of extraction within the concession.

Following the implementation of more responsible logging practices in 2002, a more homogeneous forested landscape and a smaller degree of fragmentation (i.e. smaller NP, ED, and CA for the non-forest class, an increased CONTAG and

[6] This file was acquired through the Peruvian National Institute of Natural Resources-INRENA.

GYRATE, and increased CLUMPY, LPI, and CA for the forest class) is expected to prevail. With the ending of the grace period in 2006, an increase in heterogeneity thereafter in the forest landscape or a larger degree of fragmentation (i.e. larger NP, ED, and CA for the non-forest class and smaller CONTAG, GYRATE, CLUMPY, LPI, and CA for the dominant class, which in the study area is forest) is expected. If timber concession holders have the financial capacity to pursue and comply with all the new regulations and law enforcement is successful, homogeneity in the forest landscape and a lower degree of fragmentation is expected. However, if the lack of law enforcement and non-compliance of the new regulations occur (i.e. sustainable timber management is not practiced), heterogeneity indicative of deforestation is expected.

Results

In order to understand how timber -allocation forest policies affect LCCs and changes in fragmentation patterns in a predefined timber concession area, temporal dynamic of landscape- and class-level metrics results are provided. Landscape- and class-level metrics reveal the indices of the spatial composition and configuration of the landscape and capture representative patterns through distinctive degrees of landscape heterogeneity and fragmentation. This section follows the discussion by linking the results with the established timber-allocation forest policies over time.

Changes at the Landscape Level

Table 3 presents the changes in landscape patterns (landscape-level indices) for the selected timber concession areas by year, which allows comparing the grace period with the post-grace regular compliance period. Overall, large forested patches dominate the selected timber concession area through time. The large stable patch and contagion indices demonstrate relative homogeneity and dominance of homogeneous forested landscape. However, when comparing the years 2003–2006 with 2008–2010, major changes in some of the landscape pattern indices are distinguished. For example, in 2003 NP and ED do not display a drastic increase in comparison with the baseline year (2001) and subsequent years, which could be related to the more homogeneous forest area following the implementation of more responsible forest management practices after 2001. However, by 2008 NP has drastically increased.

ED is higher for 2008, indicating a more fragmented forest area by the end of the grace period. GYRATE shows the inverse pattern to ED in 2003, displaying a slightly homogeneous forest, and considerably less homogeneity in 2008 (with a discontinuing trend into 2010). GYRATE is further correlated with LPI, meaning the larger the patch, the larger is the radius of gyration.

CONTAG, or aggregation of patches, is high when there are large aggregated patches on the landscape and low when there are many small clusters. This variable changes little in value throughout the comparative period of analysis, indicating a more or less stable forest between 2001 and 2010, followed by a slight decrease in 2008. Overall, the indices capture a more heterogeneous forested landscape trend

Table 3 Changes in landscape pattern indices for selected timber concession areas for the Tahuamanu and Tambopata provinces, Madre de Dios, period 2001–10

Metric indices	2001	2003	2006	2008	2010
Number of patches (NP)	19,879	21,636	35,131	67,209	47,080
Largest patch index (LPI)	25.65	25.65	25.62	25.41	25.57
Radius of gyration (GYRATE)	25.97	24.82	21.42	20.60	21.68
Contagion (CONTAG)	73.88	73.81	73.46	72.04	72.85
Edge density (ED)	2.57	2.64	3.56	6.92	4.83

prior to the forest-policy regime implementation in 2001, while by the end of the granted grace period in 2008 effects of timber-forest allocation policies could be linked. Notably however, the exogenous changes in the metrics after 2008 could be related to reactions to the global economic crisis, which caused a slowdown of timber production in Southeastern Peru (Urrunaga et al. 2012).

Changes at the Class Level

According to CA, secondary forest increases from 2001 to 2003 and increases further by 2006, suggesting forest regeneration occurs during the initial implementation period of more responsible forest management practices (Table 4). On the other hand, the rate of change of non-forest is considerably higher after the granted grace period than during it. Although NP in forest decreases by 2003, the amount of NP in secondary forest increases threefold in 2003, further doubling until 2006, which hints at another sign of forest regeneration. The year 2008 shows a drastic increase in NP in SF accompanied by an almost equal amount of NP in NF. At the NF class level, CLUMPY displays a rather disaggregated pattern during the first and second phases of analysis with slight peaks in 2003 and 2008. At the SF class level, CLUMPY follows an especially disaggregated pattern from 2003 to 2010. The patch extent of SF hardly changes according to GYRATE, whereas F increases from 2001 to 2003 and then continues to decrease until 2008. This finding suggests that other classes such as SF and NF are extending across the landscape and contributing to the process of fragmentation.

Using ground control points to verify land cover data, accuracy assessments were performed for the 2003 and 2010 images, revealing an overall accuracy of 90 % for the 2003 image classification and 95 % for the 2010 image. Overall, the selected forest-concession contract areas are still dominated by large and stable forested patches, as shown by 2001 to 2010 LCC maps (Fig. 2).

Discussion and Conclusion

A relationship was found to exist between the development of Peru's forestry policy framework – particularly the establishment of SFM practices, recent logging history in the provinces of Tahuamanu and Tambopata – and changes in forest landscape.

Table 4 Changes in class pattern indices for selected timber concession areas for the Tahuamanu and Tambopata provinces, Madre de Dios, 2001–2010

Class pattern index	2001	2003	2006	2008	2010
Number of patches NP					
Forest	391	293	395	468	411
Non-forest	13,207	11,100	12,728	29,770	23,664
Secondary forest	2,021	8,056	19,761	34,547	21,144
Class area CA (ha)					
Forest	991,664	991,726	990,052	981,323	987,133
Non-forest	1,917.5	1,510	2,040.6	7,929.1	4,945
Secondary forest	281.6	1,118	2,043.3	3,851.3	2,632.7
Rad. of gyration GYRATE (m)					
Forest	276.5	334.1	262.4	227.5	263.4
Non-forest	17.1	16.7	17.5	20.4	19.2
Secondary forest	16.9	16.9	15.4	15.6	16.3
Clumpiness CLUMPY (%)					
Forest	.99	.99	.99	.98	.99
Non-forest	.17	.16	.23	.37	.30
Secondary forest	.15	.14	.05	.07	.11

Landscape heterogeneity as well as degree of fragmentation fluctuated during both 2003–2006 and 2008–2010. Prior to the implementation of more responsible forest management practices, poor law enforcement and weak administrative authority led to overexploitation of the forest (Cossío 2009; Chirinos and Ruíz 2003). After 2002, there seems to have been a more homogeneous trend in the fragmentation pattern, but only until 2006. This development could be related to two major events: (1) the granting of long-term concession contracts for timber harvesting that required detailed management plans in 2002 (Cossío et al. 2011a) and (2) the implementation of a regime of discounts for concessionaires to facilitate the management of their forests between 2002 and 2006 (Cossío 2009).

As the first 5 years of the implementation of the concession system progressed, a lack of financial, physical and human capital on the part of many concessionaires became evident. This hampered their ability to fulfill their management obligations and take advantage of the benefits of the new forestry model (Cossío et al. 2011a; DAR 2012), which could explain the higher NP and ED and smaller CA for forest areas in the 2006 image. In addition, inefficient enforcement and control by the National Institute of Natural Resources (INRENA) prompted much illegal logging inside some forest concessions (World Bank 2006, 2007; Galarza and La Serna 2005), which led to an increase in non-forest areas.

The end of the year 2006 marked the end of the grace period of discounts to concessionaires and the requirement for all timber concessions to provide forest inventories. Owing to the limited capacity of many concessionaires to comply with these new requirements, fewer of them had their AOPs approved (in comparison with 2006) (Cossío 2009; World Bank 2007). In addition, the Timber Forest

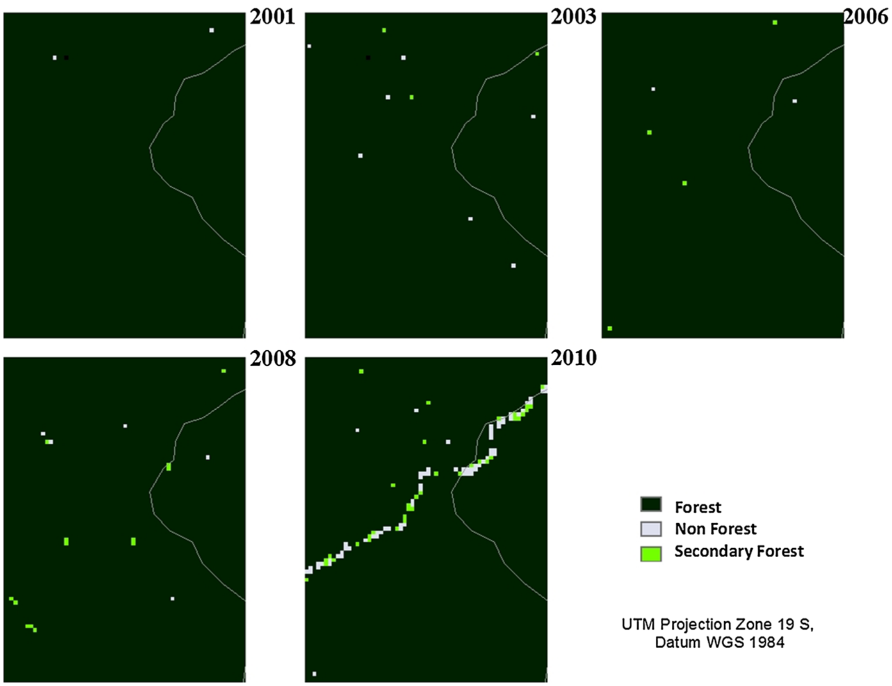

Fig. 2 Land-cover change within the timber concession study area, Madre de Dios, 2001–2010

Resources Supervision Agency (OSINFOR), which was created in 2005 to supervise and control the fulfillment of timber concession contracts, increased its periodical verification in the field of forest management plans, for which fewer AOPs were also approved. Thus, the image of May 2006 shows a more homogeneous landscape, corresponding to a lower NP and ED in comparison to following years, most probably because of these changes.

At the end of 2008, the global economic crisis affected the forest sector, reducing demand for wood, investments in SFMEs, and leading to a rise in illegal logging (FAO 2009; Urrunaga et al. 2012). According to a timber concessionaire survey, in Madre de Dios the already limited financial and managerial capacity of many timber concessionaires was aggravated and many of them reported being unable to fulfill their concession contract obligations ever since. Thus, fewer contracts were approved in 2008 and less timber legally harvested (Cossío et al. 2011a, b). Moreover, in December 2008 a process of the transference of forest functions from INRENA to regional governments began (DS No. 030-2008-AG). In Madre de Dios, this process involved changes in personnel, which delayed the evaluations and approvals of AOPs (Chucos 2011).

The management of forests remains a challenge in the study area (Sabogal et al. 2008; Defensoría del Pueblo 2009). The 2000 FWL served to empower small loggers to take more responsibility for managing state forests. In addition, the new framework constituted a step forward in the better management of Peruvian forests.

Many SFMEs were able to comply with the new regulations at first, but faced many organizational and managerial challenges afterwards.

In Peru, the forestry sector faces several constraints that need to be understood within the broader picture. Local groups that engage in timber extraction are exposed to weak rural economies that show slow economic returns from timber-related activities. Owing to the lack of formal financing for these groups, they engage in a patronage system referred to as *habilitación,* a form of debt peonage controlled by industrial logging companies (Bedoya Garland and Bedoya Silva-Santisteban 2005). This system existed prior to the forestry reform, but it has now resurfaced in many cases (Urrunaga et al. 2012; Sears and Pinedo-Vasquez 2011). Consequently, local groups that are employed by timber concessionaires show weak desire to engage in more responsible forest management practices and prefer to continue their routine informal timber extraction processes (CESVI 2005; Huertas Castillo and García 2003). This is especially the case if there are other ways such as laundering timber from private land, indigenous communities, or even protected areas (World Bank 2007; EIA 2009a) and when no legal action against violators is pursued (Urrunaga et al. 2012; Goncalves et al. 2012). A new prioritization of the forest policy is required that addresses the currently described scenario, especially if Peru plans to engage in forest conservation and management that conform to the reduction of carbon emissions from deforestation and degradation negotiations.

The assessment of the forest policy framework through timber-concession allocation policies by incorporating changes in landscape and spatial pattern techniques considerably improves understanding of the impacts of complex policies on the environment. Some limitations facing such analysis need to be considered. For example, the analyzed timber concessions may have not been the only representative concessions for linking changes in forest policies with those in landscape dynamics.

This study has linked LCC with policies, but was unable to measure specific forest practices on the ground. Other more complex processes could be causal factors behind land-use decisions that transform the landscape (e.g. levels of technological expertise, credit availability, managerial capacity, adherence to norms). Although the 2000 FWL sought to re-establish and monitor forest-harvesting practices, its implementation has been characterized by inadequate state planning and management, a lack of supporting financial capital, and insufficient business and forest management experience among SFMEs (Cossío 2009; World Bank 2007). Moreover, the control system for commercial forest harvesting is regulated by fluctuating norms and decrees that mostly benefit larger export-oriented extractors (World Bank 2007; EIA 2009a). Regulatory agencies admit lack of necessary resources, as well as technical and administrative capacities for efficient implementation. An environment without conditions of security, stability and fair competitiveness has obviously constrained better forest management practices in Southeastern Peru (Smith et al. 2006; Malleux 2008). These absences suggest that the effects of forest policies may actually characterize if not the inability of the state to enforce laws but the prolonged difficulties in doing so. To be certain of this, ground-based studies and collection of policy data are needed to monitor the effectiveness of the enforcement of rules that control timber extraction under concession system.

Further studies are also needed to evaluate the extent of forest policy impacts on forest structure and composition in relation to the loss of biomass density. This would entail the measurement of forest degradation changes through a defined transition in space and time instead of general deforestation areal measurements. Improved remote sensing techniques coupled with a better understanding of the relationship between forests and their carbon stocks, particularly from the viewpoint of reduced emissions from deforestation and degradation, are needed (Putz and Redford 2010). In addition, the impact of policies could be complemented with the assessment of spatial land-use environmental characteristics (Salo and Toivonen 2009; Hammond and Zagt 2006).

The findings presented here provide crucial data on the pattern and rate of forest transformation at a critical scale level (and in the early stages of disturbance), which help facilitate the future monitoring of a biodiversity hotspot area that is in danger of increased forest degradation and deforestation. Further, they add information to policy discussion on sustainable forest management systems.

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